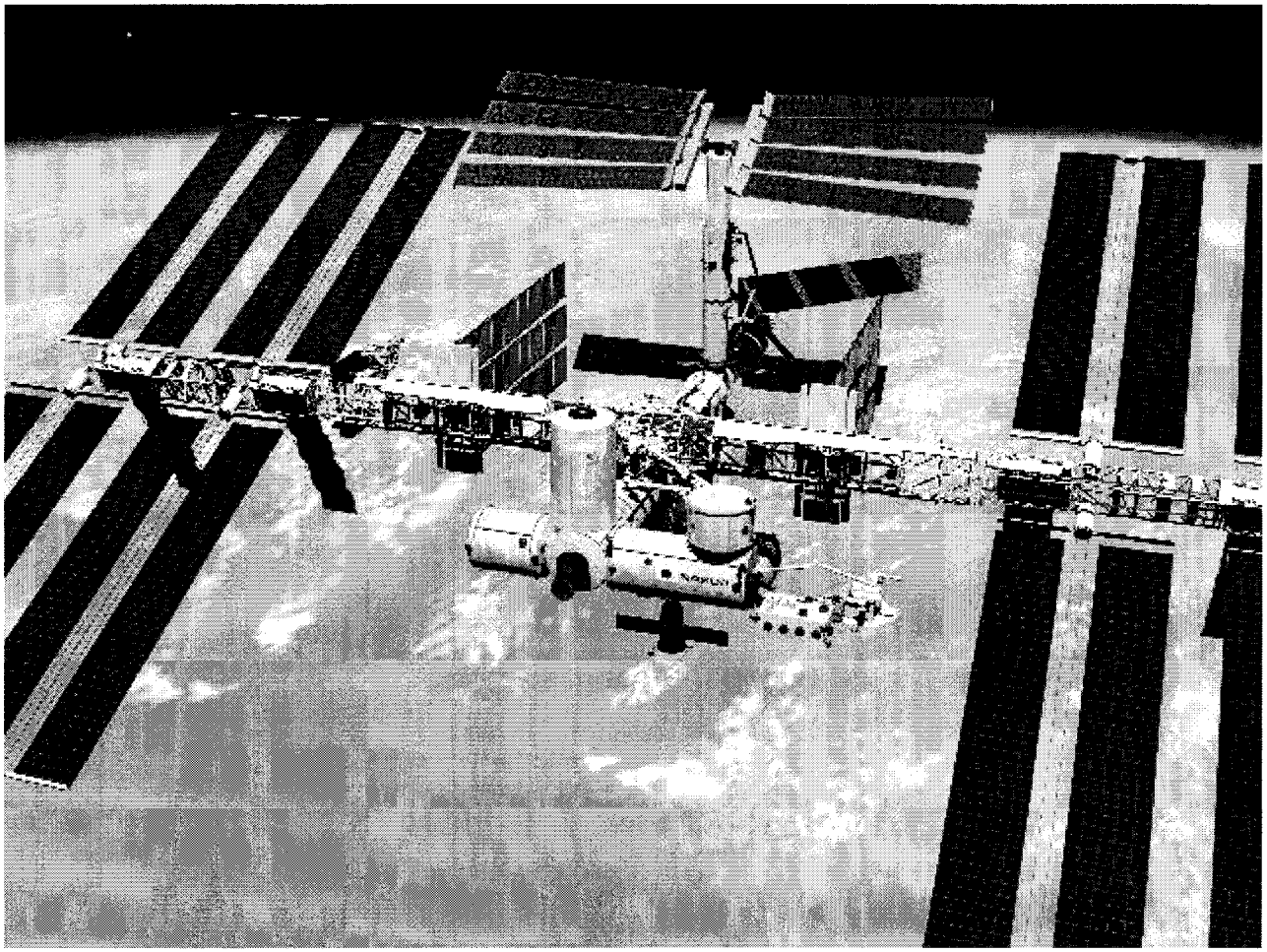
Clock Technology Development in the Laser Cooling and Atomic Physics (LCAP) Program

Dave Seidel, R.J. Thompson, W.M. Klipstein,
J. Kohel, L. Maleki

Time and Frequency Sciences and
Technology Group

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
U.S.A.



JPL

Credits

JPL: LCAP program

Dave Seidel (Systems Engineer)
Rob Thompson (Instrument Manager)
Lute Maleki (Group Sup./Proj. Scientist)
Jim Kohel
Bill Klipstein

GPS Carrier Phase:
Larry Young
Sien Wu

Project Management:
Mike Devirian (Program Manager)
Gail Klein (Project Manager)
Ed Dobkowski (Quality Assurance)
Ulf Israelsson (Discipline Scientist)
Richard Beatty (ISS Program Engineer)

Yale: GLACE, RACE, LCATS

Kurt Gibble

NIST: PARCS, LCATS

Don Sullivan
Tom Heavner
Leo Hollberg
Steve Jefferts
John Kitching
David Lee
Judah Levine
Dawn Meekhof
Craig Nelson
Tom Parker
William Phillips
Hugh Robinson
Steve Rolston
Fred Walls
Andrea De Marchi (Torrino)

CU: PARCS, LCATS

Neil Ashby

SAO: PARCS

Bob Vessot
Ed Mattison

JPL

Overview of LCAP Flight Projects

International Space Station

•PARCS (Primary Atomic Reference Clock in Space): NIST/CU
Laser-cooled cesium primary frequency standard (10^{-16} accuracy) operating continuously for at least 30 days, with GPS capability. Will perform relativity experiments and global precise time distribution.

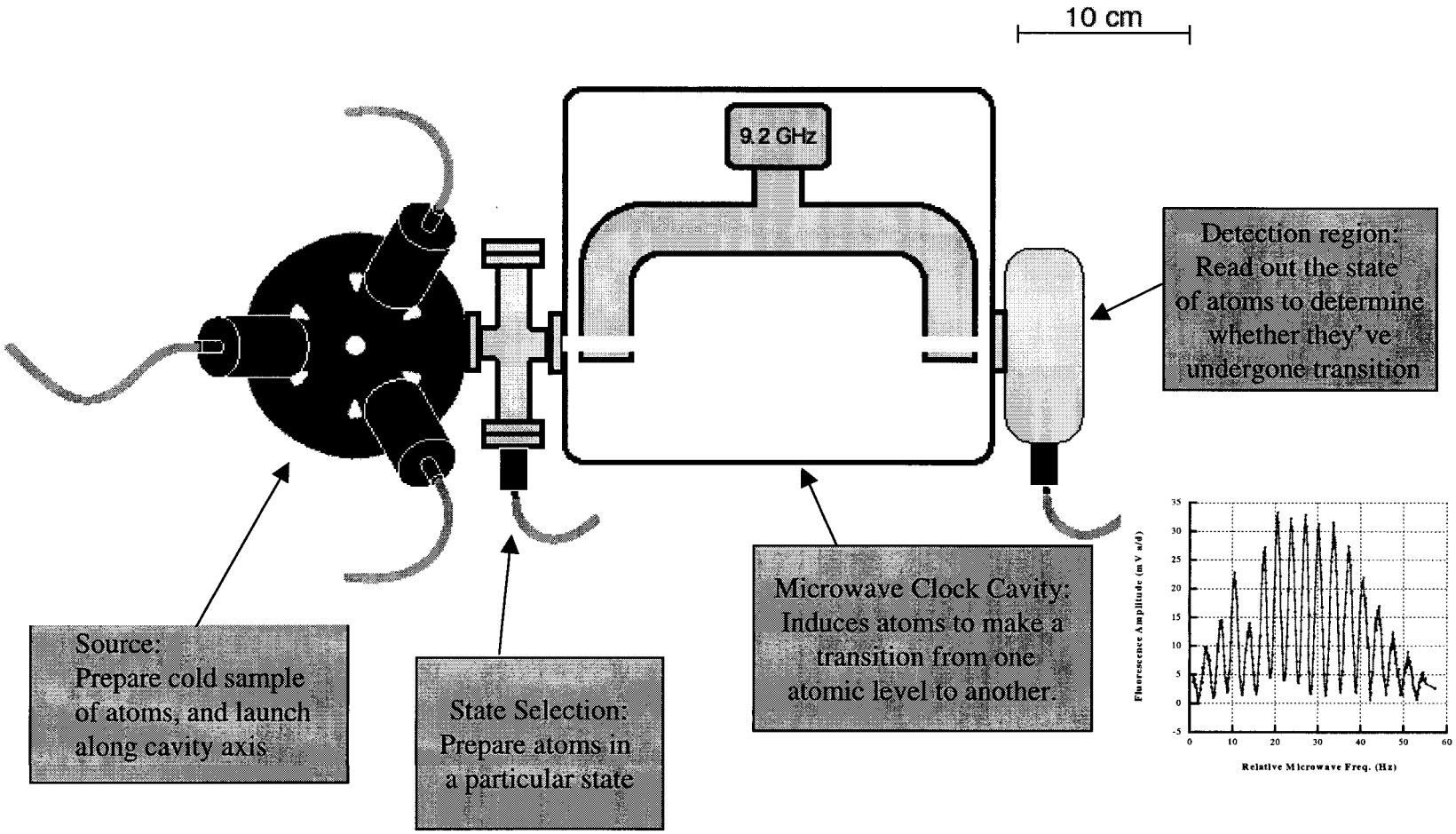
•RACE (Rubidium Atomic Clock Experiment): Yale
Laser-cooled rubidium clock for ultrahigh accuracy (exceeding a part in 10^{16}), to operate continuously for at least 30 days. Use of clock for relativity experiments and cold collision studies.

Space Shuttle

•LCATS (Laser Cooled Atomic Timekeeping in Space): Joint PARCS/RACE team.
Flight of laser-cooled microgravity atomic clock along with high stability ion clock/H maser and GPS capability for relativity experiments, tests of spatial isotropy. Tests time transfer and clock technology with some science return.

JPL

Space Clock 101



JPL

Physics with Clocks in microgravity

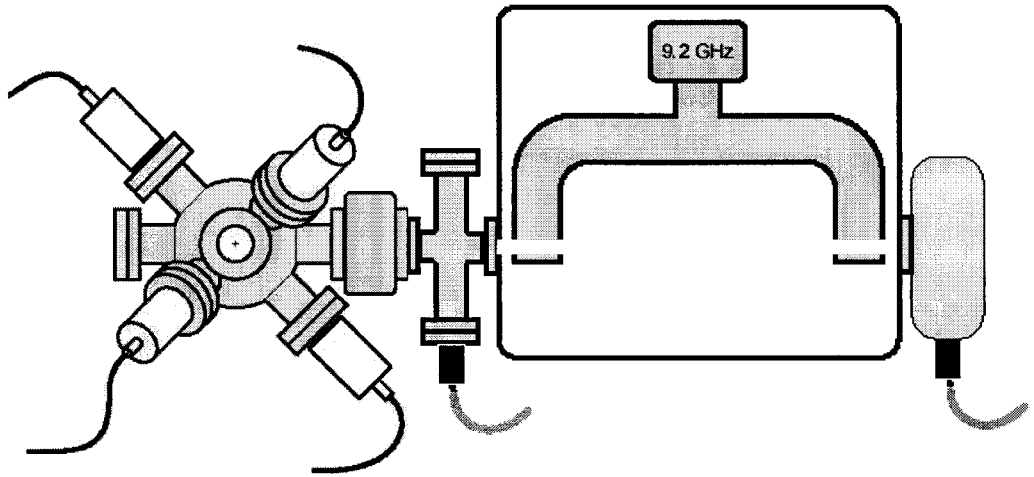
- Gravitational frequency shift (requires stable frequency transfer to ground)

- Local Position Invariance (requires comparison to another oscillator)

- Kennedy-Thorndike Experiment (requires cavity oscillator such as SUMO)

JPL

Space Clock Challenges



Laser Cooling Source

- Lasers
- Optical Frequency Control
- Fibers
- Fluorescence detection
- Vacuum chamber
- Computer Control
- Electronics
- Magnetic field control
- Atom Source

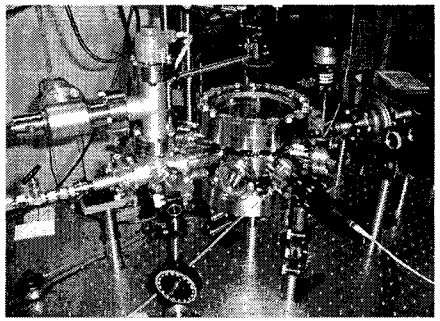
Clock Parts

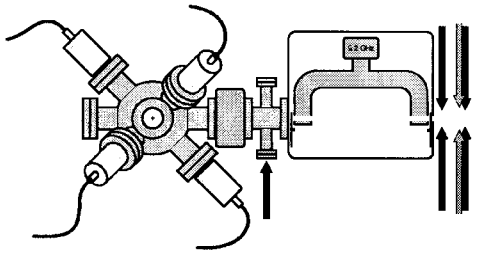
- Microwave electronics
- Local Oscillator
- Synthesizer
- Cavity
- More magnetic field control
- Thermal Control
- Light Baffling/Shutters
- Vacuum requirements
- Measurement System

JPL

JPL

LCAP Timeline



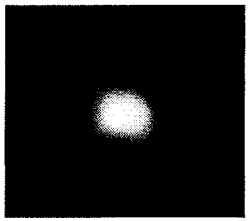


JPL Laser Cooling Facility created

Mar 97

Oct 97

First trapped Cs images at JPL



Two Flight definition projects selected from '96 NRA (PARCS and RACE)

Nov 97

Jan 99

PARCS project passes its Science concept review.

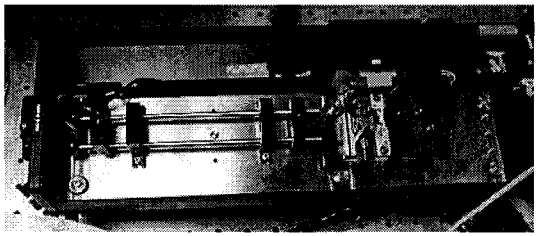
Space Qualification of components complete

Ground-based prototype clock operational

Sept 00

May 01

Engineering model complete. Critical Design review.



Flight Unit complete. Astronaut training begins

Sept 02

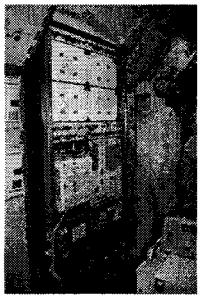
Sept 01

Launch

Mar 03

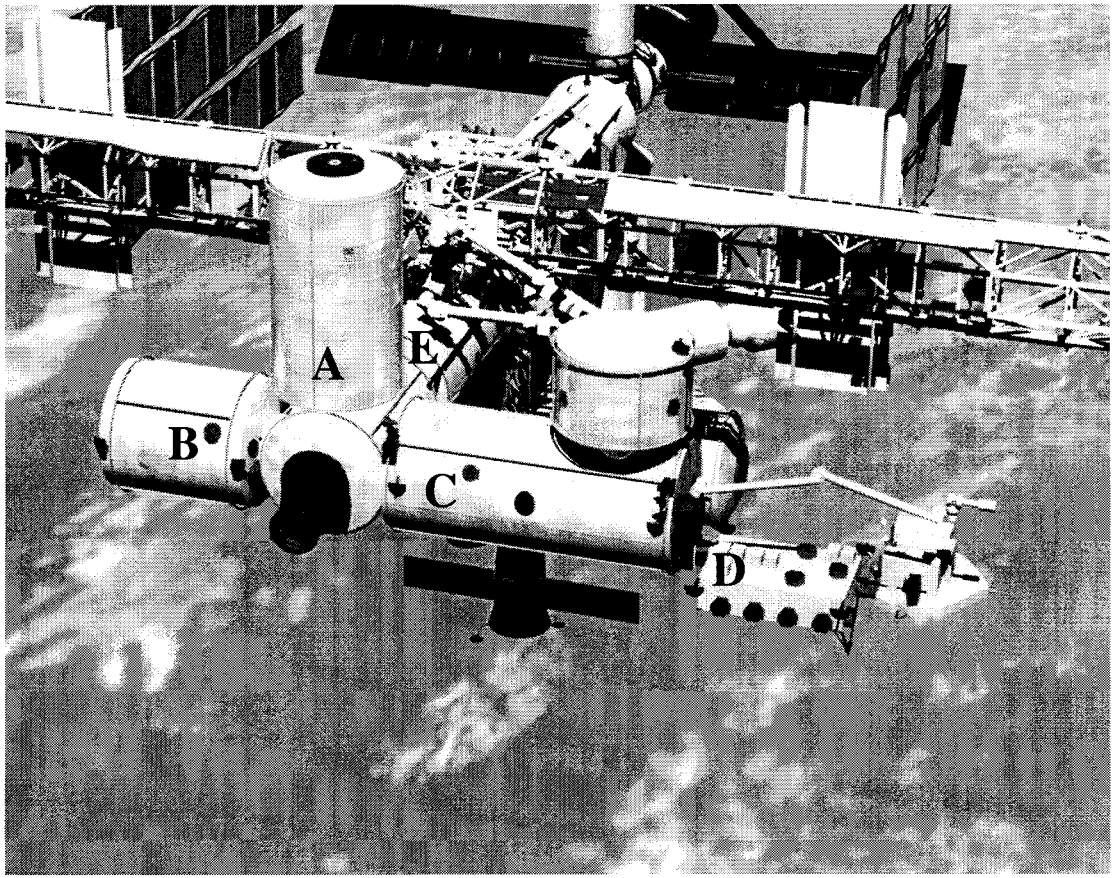
May 03

Integration into Express Transportation Rack



JPL

ISS Science Platforms



A) Centrifuge Accommodation Module

B)Columbus Orbiting Facility

C)Japanese Experiment Module (JEM)

D) JEM external facility

E) US Lab

Not shown: Russian Laboratories, Express Pallets

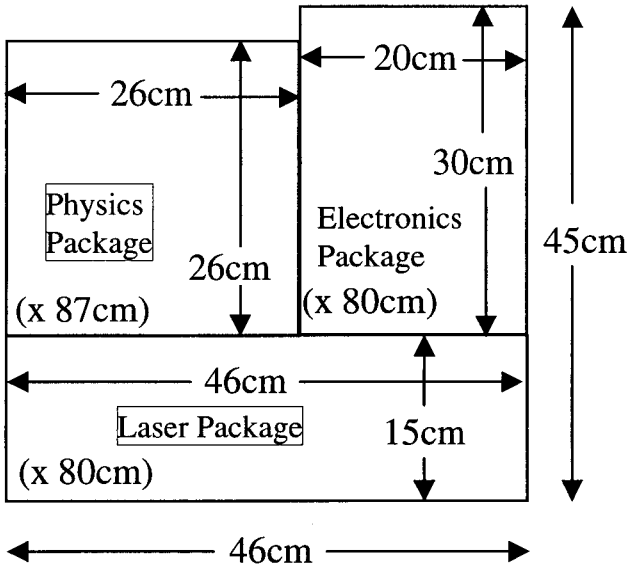
JPL

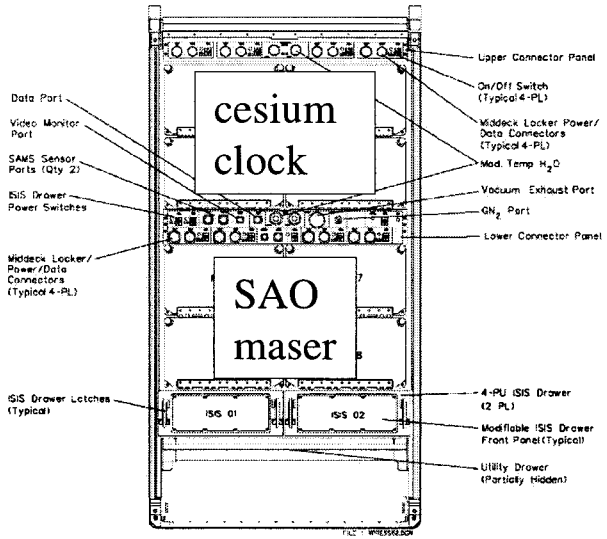
PARCS

ISS Express Rack

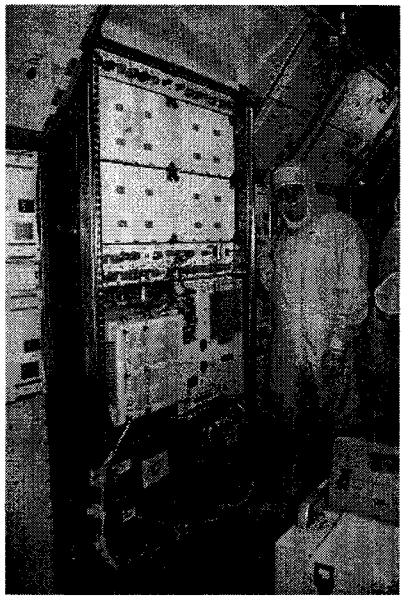
NIST JPL

Cesium Clock Package





NOTE: SAMS interface available in ARIS Rack only.



	Requirement	Constraint	Reserve
Mass	130Kg	195Kg	65Kg
Power	< 500W	<2kW	1.5kW
Volume	162 liters	248 liters	86 liters
length	87cm	90.7cm	3.7cm
depth	46cm	51.6cm	5.6cm
height	45cm	53.1cm	8.1cm

JPL

Space Qualification of Components

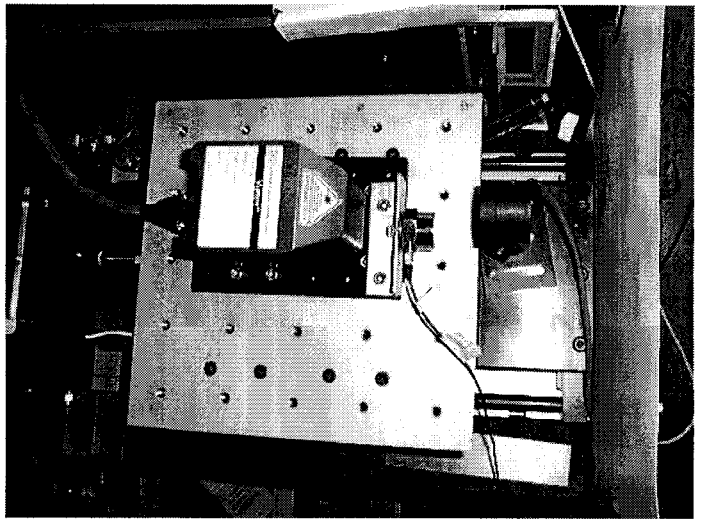
Shuttle requirements:

•Vibration Testing:

Instrument should operate after exposure to:

Freq. Range	**Design/Protoflight (PF)**	**Flight Acceptance (FA)**
20 to 150 Hz	+6dB/Octave	+6dB/Octave
150 to 1000 Hz	0.06 g^2/Hz	0.03 g^2/Hz
1000 to 2000 Hz	-6dB/Octave	-6dB/Octave

Duration: Design: 2 minutes; PF or FA test: 1 minute



New Focus Vortex laser on vibration test bed at JPL

•Environment:

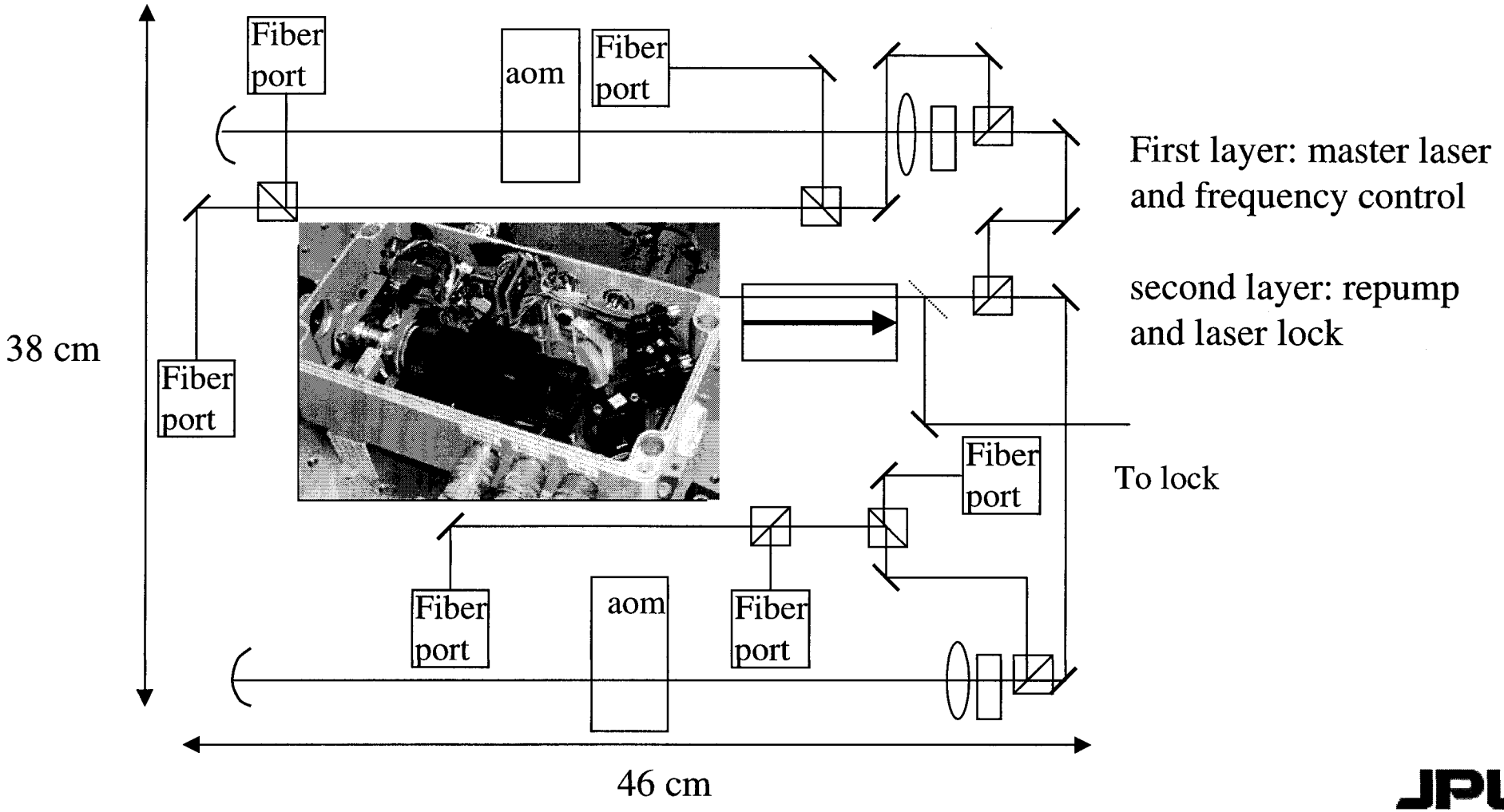
Instrument should operate after exposure to:
Temperature: -5 to 50 C
Pressure: 786 torr to 204 torr (1240 torr/min Max Depressurization rate)
Humidity: 20 to 70%

•Radiation:

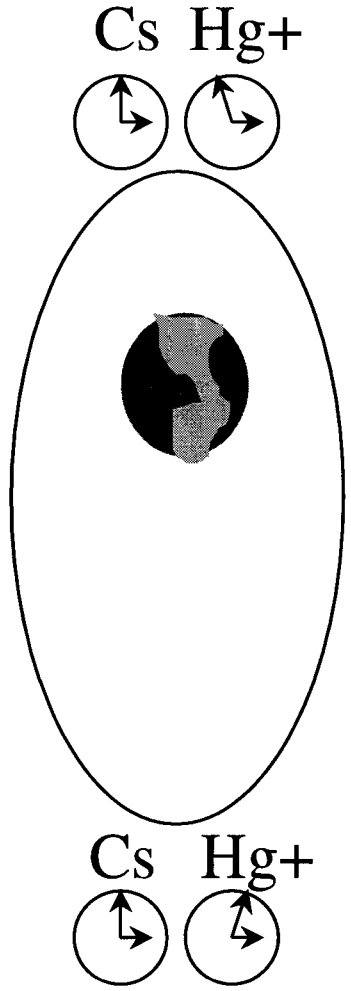
~100x Earth dose

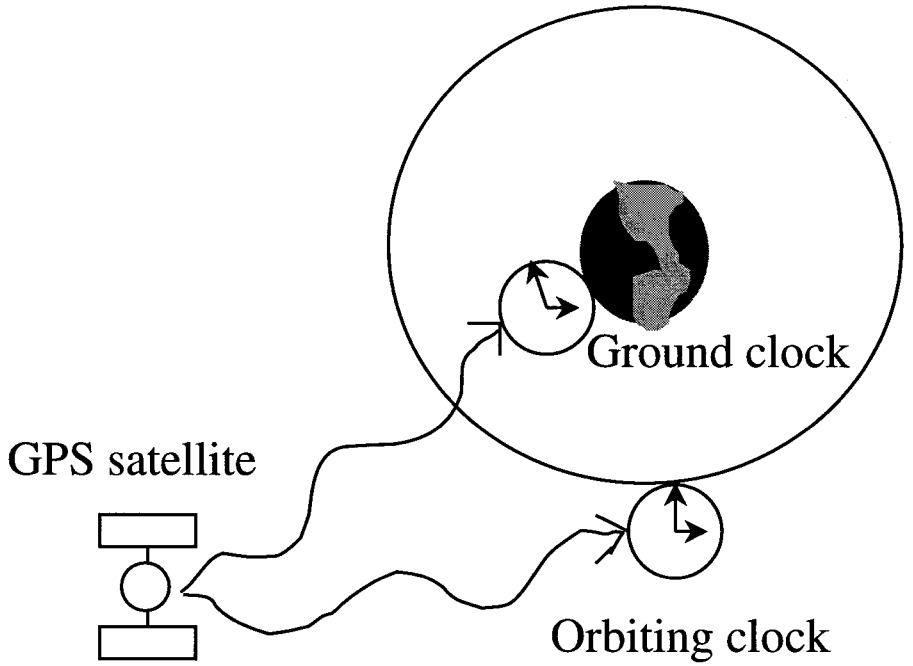
JPL

Laser Configuration



Clock Rate Comparisons: GPS Carrier Phase Frequency Transfer





JPL

GPS Carrier Phase Frequency Transfer

GPS carrier phase technique expected to give:

- 100 ps resolution
- < 10 cm position information
- < 1mm/s velocity information

Issues:

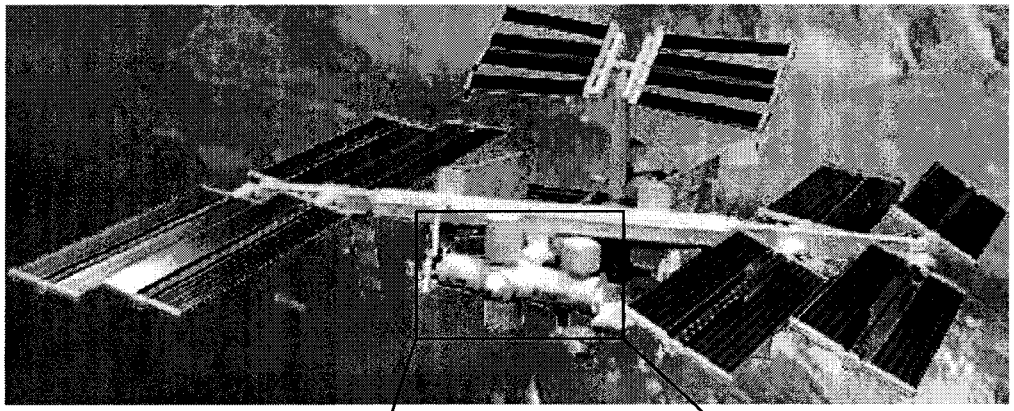
- Need external antennae
- No high quality rf/optical link between interior/exterior
- Multipath worrisome (need ~-70 dBm)
- visibility of satellites (desire ~12 in view)

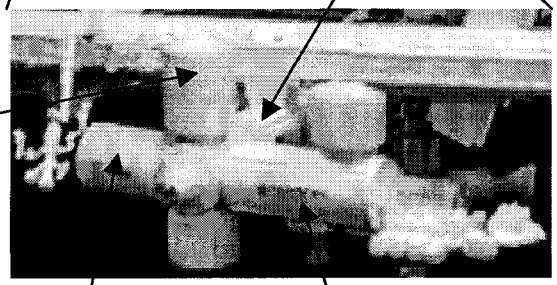
Existing GPS antennae will see between 3-6 satellites
Give Position Information to 100 m

JPL

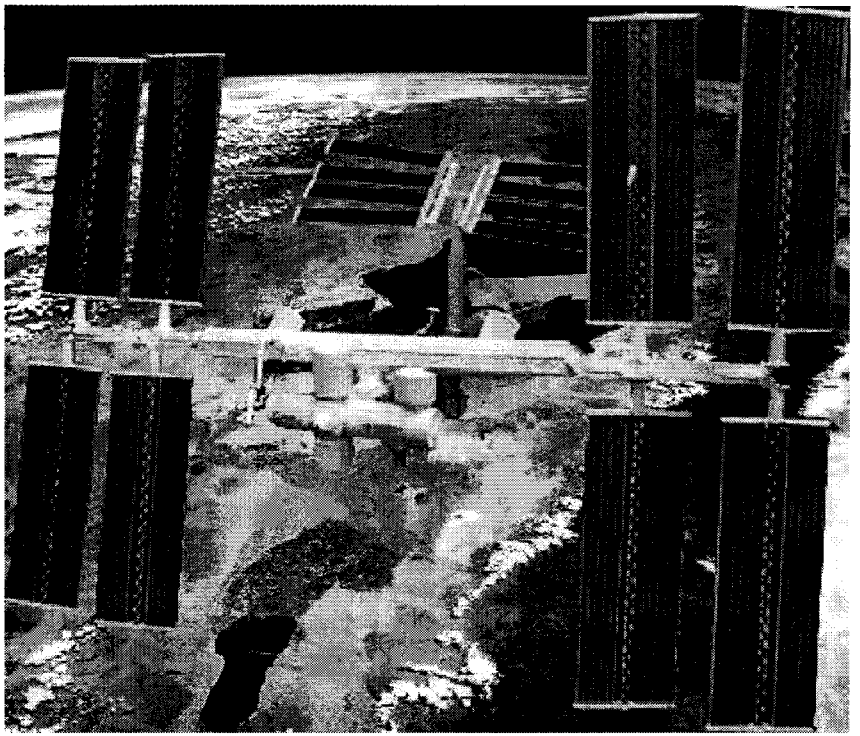
ISS Model Views

"Normal" View





Another "Normal" View



JPL